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Effects of Ecological Factors on Occupancy of Artificial Nest Boxes by the Great Tit (*Parus major*): A Comprehensive Analysis

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ABSTRACT

This study was conducted to clarify the ecological factors influencing the occupation of artificial nest boxes by the great tits (*Parus major*) in temperate mixed forests of South Korea. The occupation was determined based on the presence of the eggs and not by other field signs, such as feathers, feces, and nest materials. We conducted a habitat survey to evaluate the composition of vegetation surrounding the artificial nest boxes. The following three ecological factors affected the occupation of the artificial nest boxes: basal area, number of trees, and coverage of herbaceous plants. Occupation of the artificial nest boxes was positively affected by basal area, number of trees, and coverage of herbaceous plants. This study revealed that the availability of resources in the surrounding environment determines the selection of artificial nest boxes by the birds. Our findings may help propose management strategies to enhance the occupation of artificial nest boxes by the great tits in areas characterized by limited resources.

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DHL and SJR designed the study, wrote an edited the manuscript. DHL, TKE, JKL, HK, JHK, SHA and SJR performed field work and analyzed the data. All authors read and approved the final version of the manuscript.

Key words
Basal area, Egg, Herbaceous plants, Number of trees, Occupation, Resource

INTRODUCTION

Urbanization is a global phenomenon characterized by the continuous development and increasing urban populations (Planillo *et al*., 2020). Rapid urban growth has led to the sprawling of existing cities and creation of new urban areas (Łopucki and Kitowski, 2017). While urbanization provides living spaces for people, it also rapidly changes existing natural habitats (Leveau *et al*., 2021). Intensive development associated with urbanization leads to habitat loss, fragmentation, and degradation (Morelli *et al*., 2016). Additionally, the various city facilities cause diverse forms of pollution (Burt *et al*., 2023). Changes in habitats change due to urbanization also affects previously present wildlife (Alvey, 2006).

Many studies, particularly those focusing on birds, have examined the impact of urbanization on wildlife. These are essential for effective urban planning, conservation, and management (Plummer *et al*., 2020). Specialist and forest-dwelling birds are known to experience the negative effects of urban environments, such as reduced breeding performance, resource scarcity, light pollution, noise pollution, air pollution, and bird strikes (Loss *et al*., 2019; Arévalo *et al*., 2022). However, not all bird species are negatively affected by urbanization. Some urban-adapted species benefit from anthropogenic food resources and relatively fewer predators in urban areas (Morozov, 2022). Nevertheless, the driving impact of urbanization on wild birds is the reduction of vegetation cover (MacGregor-Fors and Schondube, 2011). Vegetation is critical because they provide nesting sites, food resources, resting places, and refuge for birds (Macchi *et al*., 2019). Although urban parks and forests managed within cities can positively affect birds, they often fall short compared to natural environments.

Secondary cavity nesters, which cannot excavate their own nesting cavities, are more vulnerable in urban spaces (Brown and Graham, 2015), wherein the scarcity of large trees leads to the absence of primary cavity nesters (Stagoll *et al*., 2012). The diminished nesting resources available for secondary cavity nesters results in an overall reduction in their population (Wesołowski, 2007). Artificial nest boxes are used to manage cavity nesters who face difficulties in urban green spaces (Sudyka *et al*., 2022) by providing nesting resources for secondary cavity nesters. Moreover, researchers gain scientific data for their

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management.

Several factors influence the occupation of artificial nest boxes by secondary cavity nesting birds. Previous studies have reported that vegetation structures affect the selection of artificial nest boxes during breeding season because they provide resources (Veselý *et al*., 2016). Furthermore, it is known that the entrance orientation affects the internal temperature of the artificial nest boxes (Ardia *et al*., 2006). Some studies have also shown that entrance orientations are closely related to the microclimates, which affect the breeding success of cavity nesters (Michael *et al*., 2009). Recently, noise and human disturbance related to proximity to roads can decrease the rates of utilization of nest boxes (Walthers and Barber, 2020). Additionally, light intensity in artificial nest boxes has influences parental preference and offspring growth rates (Cooper *et al*., 2011; Podkowa and Surmacki, 2017).

Paridae is a family of birds that frequently they highly utilize artificial nest boxes as nesting resources (Lambrechts *et al*., 2010). They are prominent secondary cavity nesters distributed across Europe and Asia (Johansson *et al*., 2013). This group includes great tit (*Parus major*), blue tit (*Cyanistes caeruleus*), marsh tit (*Poecile palustris*), coal tit (*Periparus ater*), willow tit (*Poecile montanus*), and varied tit (*Sittiparus varius*), among which great tits frequently use artificial nest boxes in South Korea (Son *et al*., 2012). Being a generalist species, these birds adapt well to various habitats and are selected as an indicator species for evaluating different environments (Morelli *et al*., 2021). Furthermore, great tits are known to have a beneficial impact as insectivorous birds, contributing to pest control (García *et al*., 2021). While many studies regarding great tit have been conducted worldwide, researches concerning the relationship between environments and their occupation of artificial nest boxes are lacking in South Korea.

This study aims to investigate the ecological factors influencing the occupation of artificial nest boxes by the great tit in mixed forests of South Korea. We formulated the following two hypotheses: Vegetation composition has an impact on nest selection of the great tits because they have the potential to be used as resources, low levels of illumination and proximity to roads are unfavorable for nest occupation because of the impact on breeding performance and predation risk.

MATERIALS AND METHODS

This study was conducted in two sites of mixed forests (37° 00.04´ N, 127° 13.96´ E) from March 2020 to July 2022 in da Vinci Campus, Chung-Ang University, South Korea. Great tit, Eurasian nuthatch (*Sitta europaea*), brown-eared bulbul (*Hypsipelia amaurotis*), and Eurasian tree sparrow (*Passer montanus*) are the dominant bird species, and Rigida pine (*Pinus rigida*), Japanese red pine (*Pinus densiflora*), and ginko (*Ginko biloba*) are the dominant trees in this area. The annual mean temperature and annual precipitation during the study period were 12.47 °C and 1257.50 mm, respectively (Korea Meteorological Administration, 2023). The altitudinal gradient range is 40−50 m above sea level.

In each of the two sites, 48 artificial nest boxes, each of size 15 × 13 × 26 cm were installed 1−2 m above the ground (Hwang *et al*., 2017). The distance between the artificial nest boxes was maintained at a minimum of 30 m (Rhim *et al*., 2011), and a GPS device (Garmin GPS64) was used to record their locations. Before the commencement of each year's field survey, the previous year's artificial nest boxes were cleaned, and any damaged boxes were repaired or replaced. Occupation was determined based on the presence of the eggs and not by other field signs (feathers, feces, and nest materials). The entrance orientation of 96 artificial nest boxes were set to be the same, 24 each for north, south, east, and west. Visits to the nest boxes were conducted three times a week in the morning consistently throughout the experimental period to monitor their usage.

We conducted a habitat survey to evaluate the composition of vegetation surrounding the artificial nest boxes within a radius of 5.64 m around each nest box (Lee *et al*., 2017). The coverage of bare land (only soil covers without vegetation), herbaceous plants (grasses, ferns, and mosses), shrubs (woody plants that have multiple stems arising from the base), and downed trees were measured to estimate the vegetation components. The number of trees with diameter at breast height (dbh) > 6 cm and basal area (cross-sectional area of trees at breast height) were used as variables. The internal illumination of artificial nest boxes were also measured using a lux meters (TESTO 540). Light measurements were conducted three times a week, and the average value calculating for each year was used. During each visit, three measurements were taken for every artificial nest box, and the average value was recorded. The distance between artificial nest boxes and roads was measured using QGIS software (version 3.22), thus determining the distance between each artificial nest box and the nearest road. Field surveys were not conducted in extreme weather conditions, such as rain and strong wind.

Before the analysis, Spearman's correlation analyses were conducted to determine multicollinearity among the independent variables. Based on a previous study, we discarded a pair of variables that had a Spearman's correlation coefficient > 7 (Suttidate *et al*., 2019). Between the highly correlated two independent variables, we selected variables that have a high correlation with the dependent variable or with more ecological meanings (Lee *et al*. 2020). During this process, the coverage of shrub variable was removed.

We used a generalized linear mixed model (GLM) to test our hypothesis using the 'lme4' package (Bates *et al*., 2015) in R (R Core Team, 2023). The global model was as follows: Occupation ~ coverage of bare land + coverage of herbaceous plants + coverage of downed trees + basal area + number of trees + internal illumination + distance from road + entrance orientation + year + nest ID. The dependent variable was the occupation of artificial nest boxes; therefore, the model was set with a binomial distribution. The "dredge" function from the "MuMin" package was used to select the model with the lowest corrected Akaike information criterion (AIC*c*) value among the candidate models (Bartoń, 2016). Statistical significance was set as $p < 0.05$.

RESULTS

In this study, we monitored total 288 artificial nest boxes (96 nest boxes for 3 years), of which 82 were occupied during the study period. Monitoring of the incubating parent birds and chicks revealed that all artificial nest boxes were occupied only by the great tits. We compared the mean daily temperature and precipitation levels from March 2020 to July 2022 using the Kruskal–Wallis test to investigate the potential impact of climatic factors, although this was not included in the analysis. The mean daily temperature (mean±SE) was 16.52±0.58℃ in 2020, 17.24±0.59℃ in 2021, and 17.22±0.62℃ in 2022. However, there was no significant differences in temperature over the three years (χ^2= 0.94, p= 0.64). Similarly, the mean daily precipitation level (mean±SE) was 4.00±1.10 mm in 2020, 2.90±0.66 mm in 2021, and 2.93±0.81 mm in 2022, and there was no significant difference between them (χ^2 = 1.81, p = 0.41).

To examine the influence of independent variables, we used GLMs and selected three models with an AIC*c* value < 2 (Table I). The three models used to study occupation of artificial nest boxes by great tits included four ecological factors: Coverage of herbaceous plants, basal area, number of trees, internal illumination. Models A, B, and C included four, three, and two independent variables, respectively.

The best model among the three was selected based on the lowest AIC*c* value, and the effects of each independent variable were described. In the best model, coverage of herbaceous plants (β= 0.02, Z= 2.38, OR= 1.02, p= 0.04), basal area (β= 0.31, Z= 4.04, OR= 1.37, p < 0.01), and number of trees (β= 0.12, Z= 2.11, OR= 1.13, p = 0.04) significantly differed, while internal illumination (β= −0.10, Z= −1.94, OR= 0.90, p = 0.16) did not (Table II).

Table I. Generalized linear models (GLMs) to determine ecological factors affecting the occupation of artificial nest boxes by the great tit (*Parus major*).

Model	AICc	ΔAICc	w_i	K
[Intercept + ch + bs + nt + il]	305.70	0.00	0.33	5
[Intercept + ch + bs + nt]	307.72	0.02	0.32	4
[Intercept + ch + bs]	307.42	1.72	0.14	3

This table lists candidate models with ΔAIC*c* values less than 2. w_i, Akaike weight; ch, coverage of herbaceous plants; bs, basal area; nt, number of trees; il, internal illumination.

Table II. Best model describing ecological factors affecting the occupation of artificial nest boxes by the great tit (*Parus major*).

Factors	β	SE	Z	p	OR	95% CI
Intercept	−4.81	0.86	−5.60	<0.01	0.01	(0.00, 0.04)
ch	0.02	0.01	2.38	0.04	1.02	(1.00, 1.05)
bs	0.31	0.08	4.04	<0.01	1.37	(1.18, 1.60)
nt	0.12	0.06	2.11	0.04	1.13	(1.00, 1.27)
il	−0.10	0.08	−1.94	0.16	0.90	(0.77, 0.99)

SE, standard error; OR, odds ratio; CI, confidence interval; ch, coverage of herbaceous plants; bs, basal area; nt, number of trees; il, internal illumination.

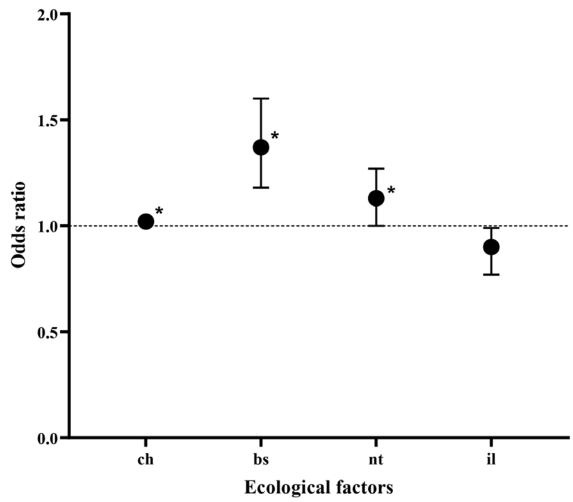

Fig. 1. The effect of ecological factors on the occupation of artificial nest boxes by the great tit (*Parus major*), determined using the best models selected from the generalized linear models. ch, coverage of herbaceous plants; bs, basal area; nt, number of trees; il, internal illumination. An asterisk indicates a significant difference (p < 0.05).

Among the statistically significant variables, coverage of herbaceous plants, basal area, and number of trees positively influenced occupation of artificial nest boxes by great tits (Fig. 1). Internal illumination showed a negative trend with dependent variables; however, it was not statistically significant.

DISCUSSION

In this study, we aimed to identify the ecological factors affecting the occupation of artificial nest boxes by great tits. The results were as following: firstly, the occupation of artificial nest boxes by great tits was related to coverage of herbaceous plants, basal area, and the number of trees; secondly, internal illumination and distance from road showed no significant relationship.

Great tits requires various resources, including food, nest material, and shelter (Drent *et al*., 2003) during their breeding season. In this study, most of the ecological variables were related to vegetation. The basal area and number of trees were found to have a positive effect. Habitats with higher proportion of basal area and greater number of trees typically indicate areas with large and old trees (Park *et al*., 2019). The richness and abundance of arthropods, which are a major food resource for great tits during their breeding season, are often high in such habitats (Cahill *et al*., 2021). Additionally, large trees provide roosting places during foraging and can contribute to the availability of moss, which is a key material for nest construction (Rydgren *et al*., 2023). Therefore, higher density of large trees can be attributed to the increased availability of resources for the birds.

Coverage of herbaceous plants, which serves as a site for foraging food resources is also positively impacted (Slagsvold and Wiebe, 2006). In mixed forests, the great tit mainly uses herbaceous plants and trees as foraging sites (Díaz *et al*., 1998). Moss, which is abundantly distributed on the ground, is the most utilized nest bed material by great tits (Britt and Deeming, 2011). It enhances the insulation of bird nests, allowing for optimal temperature regulation during incubation and brooding (Wesołowski and Wierzcholska, 2018; Deeming *et al*., 2020). Great tits prefers to collect moss nearby nest for nest-building efficiency (Rydgren *et al*., 2023). Furthermore, higher proportion of herbaceous plants indicates lower vegetation height, suggesting more open habitats (McIntyre *et al*., 2019). The higher availability of open spaces improves foraging skills of birds (Telve *et al*., 2020). Therefore, great tits prefer environments with a higher proportion of herbaceous plants because they enable efficient procurement of food and nest materials.

In our study, internal illumination was included in the best model but was not statistically significant. But in the best model, internal illumination had a negative trend on occupation of artificial nest boxes by great tits. A previous study reported that appropriate internal illumination could reduce parasitism in nest boxes and provide favorable conditions for temperature regulation of eggs and chicks (Yang *et al*., 2022). Additionally, brightness in nest boxes improves efficiency of parental care (Maziarz and Wesołowski, 2014). However, secondary cavity nesters prefer dim conditions (Podkowa *et al*., 2019) because they provide protection from predators and a stable microclimate for breeding success (Maziarz *et al*., 2017). Therefore, the preference of great tits for artificial nest boxes with low illumination is due to the prioritization of anti-predator response over parental care. Nevertheless, the results of our study did not adequately demonstrate the influence of internal illumination. In other words, it is deemed necessary to conduct subsequent studies for a more precise evaluation of the impact by internal illumination.

In this study, we found that the distance from roads did not influence the occupation of artificial nest boxes by great tits. Roadside noise has been reported to affect avian communication negatively (Patricelli and Blickley, 2006). Additionally, the areas on the edges of roads are the preferred habitats for predators; this can have detrimental effects on avian breeding success (DeGregorio *et al*., 2014). The roads used in our study area were relatively small. Therefore, they had no influence on occupation (Forman *et al*., 2002).

Coverage of downed trees and entrance orientation did not influence the occupation of the artificial nest boxes by great tits. In previous researches, arthropods are abundantly distributed in downed trees, which serve as a food resource during the breeding seasons of insectivore birds (Schieck *et al*., 1995; Lee *et al*., 2023). However, since the great tit primarily forages in trees and ground vegetation, it is judged to had no influence in the occupation of artificial nest boxes (Díaz *et al*., 1998). In some studies, the entrance orientation of artificial nest boxes is closely related to the nest's internal microclimate (Goodenough *et al*., 2008). Internal microclimate can affect the temperature fluctuation of the nest, warming eggs, and thermoregulation of chicks (Salaberria *et al*., 2014). However, due to the smaller size of the study sites compared to other studies (Zhang *et al*., 2021) and the lack of measurement of microclimates in each artificial nest box, it appears that entrance orientation did not affect the occupation.

CONCLUSION

In conclusion, we identified various ecological factors influencing the occupation of artificial nest boxes by the great tits. The birds prefer areas with high density of large trees and large proportion of herbaceous plants to ensure access to abundant food resources and nest materials. This strategy is likely to maximize breeding success. Since our study focused only on the great tits, further studies are required to determine preferred environments for other secondary cavity nesters. Additionally, long-term ecological studies regarding breeding outcomes in preferred environments are necessary for the conservation and management of secondary cavity nesters in urban forests.

DECLARATIONS

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Ethical statement

Research experiments conducted in this article with animals were approved by Institutional Animal Care and Use Committee, Chung-Ang University (Approval number: CAU 2017-00095) followings all guidelines, regulations, legal, and ethical standards as required for animals.

Statement of conflict of interest

The authors have declared no conflict of interest.

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